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14. ABSTRACT

A series of experiments was devised that involved both generic sub-scale munitions and carefully designed cased cylinder surrogates. Three tests of each configuration were performed producing measured airblast fields of peak pressure and peak impulse for each. These airblast fields were then inspected to determine if the cased cylinder surrogates produced an airblast field that was satisfactorily similar to the generic sub-scale munition. A description of these experiments and a discussion of the results are presented in this paper.

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Surrogating Sub-Scale Munitions With Simple Cased Cylinders For Airblast Prediction Purposes

By

Edward J. Blaney
Alan P. Ohrt

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Edward J. Blaney
Air Force Research Laboratory
Munitions Directorate
Eglin AFB, FL

Alan P. Ohrt
Air Force Research Laboratory
Munitions Directorate
Eglin AFB, FL

Historically, attempting to gather airblast measurements (pressure and impulse) around cased munitions has been very risky and expensive due to the damaging nature of high-velocity fragments, which in many cases precede the arrival of the shock wave being measured. Facilities such as the Instrumented Blastpad, built by the Air Force Research Lab, Munitions Directorate (AFRL/MN) at Eglin Air Force Base, Florida, now provide the capability to acquire these measurements without placing the instrumentation hardware at risk from fragment strike. However, there is still considerable cost associated with the manufacture of exact sub-scale models of inventory munitions due to the complexity of their shapes (non-cylindrical bodies, internal and external ogives, etc). Furthermore, it is desirable from a modeling and simulation standpoint to be able to accurately characterize a wide range of munition shapes with a few simple devices. As a result, sub-scale munition bodies are often surrogated as simple, right circular-cylinders. It is then assumed that the airblast field from the surrogate "cased cylinder" would be very similar to that of the realistic sub-scale munition. Cased cylinders have the benefit of being less expensive and time-consuming to manufacture, but the suitability of surrogating realistic sub-scale munitions with cased cylinders has not been firmly established with either experiment or calculation.

A series of experiments was devised that involved both generic sub-scale munitions and carefully designed cased cylinder surrogates. Three tests of each configuration were performed on the AFRL/MN Instrumented Blastpad, producing measured airblast fields of peak pressure and peak impulse for each. These airblast fields were then inspected to determine if the cased cylinder surrogates produced an airblast field that was satisfactorily similar to the generic sub-scale munition. A description of these experiments and a discussion of the results are presented in this paper.

INTRODUCTION AND BACKGROUND

Most unpowered, air-to-surface munitions in use today generally fall into two major categories: general purpose (GP), and penetration. General purpose bombs are primarily used against light, above-ground targets that are vulnerable to blast and fragmentation. The steel case of a GP bomb tends to be ovoid in shape and have thin walls, since the majority of the mass of the weapon is high explosive. Penetrators, as the name implies, are designed to pierce a heavily fortified structure and detonate inside. As a result, they tend to be more rod-shaped, have much thicker walls, and have a heavy, pointed nose to aid in penetration. A comparison of these two weapon types can be seen below in Figure 1.

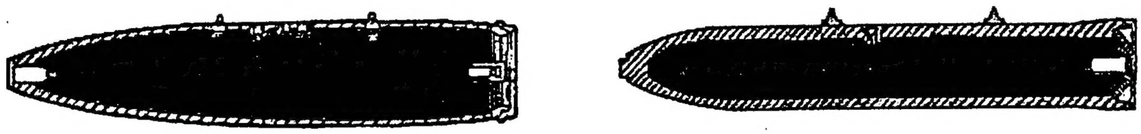


Figure 1. General Purpose (left) and Penetrator (right) Warheads [www.fas.org]

There are many variations on the shapes shown above, and attempting to manufacture small-scale versions of all of them for use in explosive testing and modeling would be impractical due to the cost of machining the internal and external shapes. In addition, explicitly modeling the exact shape of a munition in an engineering-level effectiveness code would be extremely cumbersome. As a result, sub-scale munition bodies are often surrogated as simple, right circular-cylinders. It is then assumed that the airblast field from the surrogate "cased cylinder" would be very similar to that of the realistic sub-scale munition. Cased cylinders have the benefit of being less expensive and time-consuming to manufacture, but the suitability of surrogating realistic sub-scale munitions with cased cylinders has not been firmly established with either experiment or calculation.

In an effort to determine the merits of surrogating sub-scale munitions with cased cylinders, the Air Force Research Lab Munitions Directorate (AFRL/MN) conducted a series of tests of three generic sub-scale penetrators and three carefully-designed cased cylinders on its Instrumented Blastpad, a facility designed to allow the detailed characterization of the blast field surrounding cased explosive charges. Details on the design and construction of the blastpad, as well as descriptions of several test series, have been presented at a number of public-release [1, 2] and limited-distribution forums [3, 4, 5]. However, a brief overview of the blastpad will be included here for the sake of completeness.

THE AFRL INSTRUMENTED BLASTPAD

Figure 2 is an isometric sketch of the instrumented blastpad as viewed from above. The blastpad is a roughly 42.7 m long by 24.4 m wide concrete slab which contains 70 surface flush instrumentation mounts arranged concentrically around a replaceable detonation area. The replaceable detonation consists of a steel-lined rectangular box (1.4 m long by 1.1 m wide x 0.6 m deep) positioned over a 1.8 m diameter, 2.44 m deep steel-lined pit, resulting in a total depth of just over 3 m. Instrument cables are routed through conduits beneath the pit to a junction box some distance away.

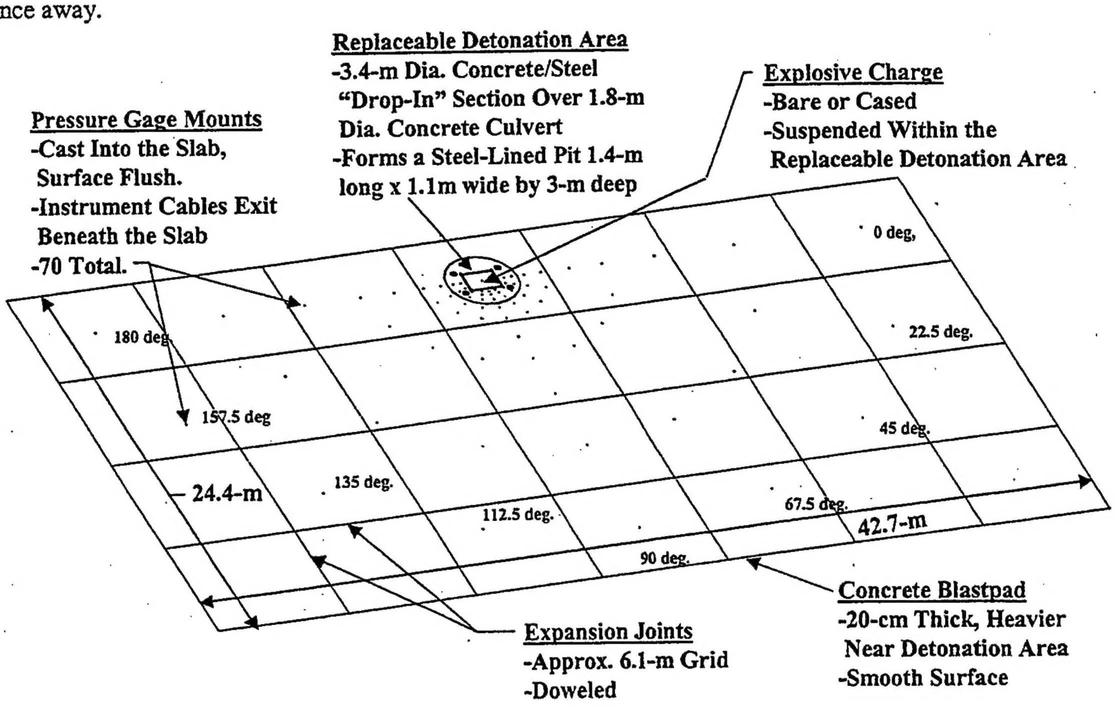


Figure 2. Isometric view of the Instrumented Blastpad.

To conduct a typical experiment, the candidate explosive charge is suspended within the replaceable detonation area (referred to hereafter as the blast pit) so that half of the explosive charge is above the plane of the blastpad surface, and half of the charge is within the blast pit. Stated differently, the equator of the explosive charge is contained within the plane of the blastpad surface. This is shown conceptually in Figure 3 with a cased explosive charge.

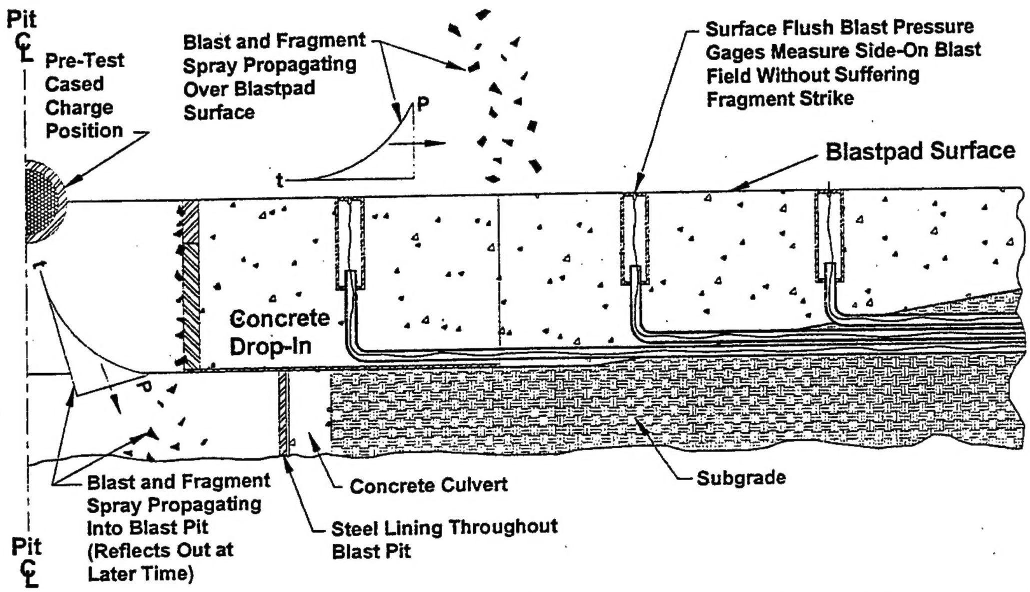


Figure 3. Cross-sectional view of the instrumented blastpad detonation area, illustrating the testing concept.

Upon detonation, the cased explosive charge expands naturally within the void space of the blast pit until the case breaks into its fragments. Blast and fragments from the upper half of the explosive charge propagate over the surface of the instrumented blastpad where the surface flush blast pressure gages measure the incident pressure from the cased explosive charge. Since the instrumentation is mounted surface flush, the measurements are not vulnerable to fragment impacts. Blast and fragments from the lower half of the explosive charge propagate into the blast pit below. Fragments strike the steel lining of the blast pit and the concrete floor, causing some damage. The steel linings are replaceable, so that the extensively damaged portions can be replaced after several experiments. Blast from the lower half of the explosive charge will propagate to the bottom of the 3 meter deep pit and reflect back up and out of the replaceable detonation area. This reflected blast is then free to diffract back over the surface of the blastpad where it would be recorded by the surface flush blast pressure gages. The delay in time of this reflected blast is sufficient, however, to fully characterize the initial direct blast from the cased explosive charge. In this way, experiments can be conducted to quantify the blast fields from cased explosive charges.

CHARGE DESCRIPTION

Two case shapes were used for the charges in this set of experiments: a generic penetrator and a right-circular cylinder. The type of explosive used (pentolite) and explosive mass (3.86 kg) inside each case was identical. The penetrator was machined from a solid billet of 4340 steel and heat-treated for additional strength. It has internal and internal ogives, and the tail end is threaded internally to accept the base plate. In order to minimize the uncertainty in the test data, it was desired that the pentolite explosive fills of the cased charges have carefully controlled masses. Since melt casting of the pentolite directly into the steel casing was likely to arrive at an imprecise weight and an uneven surface on the pouring end, another means of filling the case was pursued. A bare pentolite cylinder was cast and then machined to fit precisely within the charge casing. To assemble the final munition the machined pentolite was inserted into the charge casing. A small Composition A-5 booster was then glued to the exposed end of the pentolite charge. An exploding bridge wire detonator was inserted through the hole in the base plate and a plastic alignment fixture to achieve contact with the A-5 booster, providing the means of initiation for the cased charge. A diagram for the generic penetrator can be seen below in Figure 4.

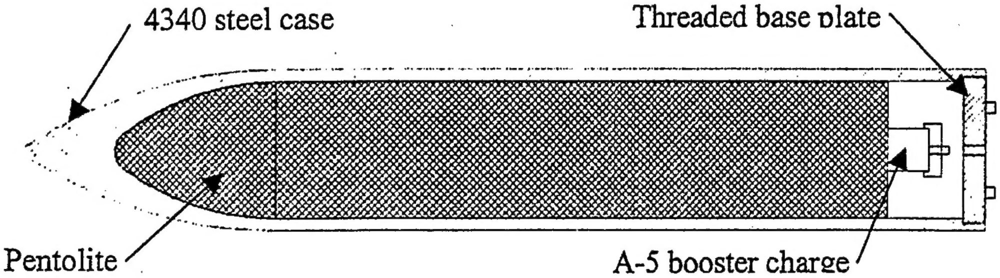


Figure 4. Cross-Section View of Generic Sub-Scale Penetrator

The cased cylinders were then fabricated to closely match the case mass to explosive mass ratio of the generic penetrators. Two slightly different definitions of this ratio were considered in the design. First, there is the ratio of the total mass of the metal case to the total explosive mass, m_c/W. A different ratio, M/C, compares the metal-to-charge ratio of a unit thickness portion of only the cylindrical section of the weapon. This ratio ignores the presence of any steel at the nose or tail of the weapon. Both mass ratios for the cased cylinders are identical to those of the generic penetrators. The pentolite insert in the cased cylinder was machined using the same process as for the penetrators, though in this case the explosive is purely cylindrical. The detonation train for the cased cylinders is also the same. A diagram of the cased cylinders can be seen below in Figure 5.

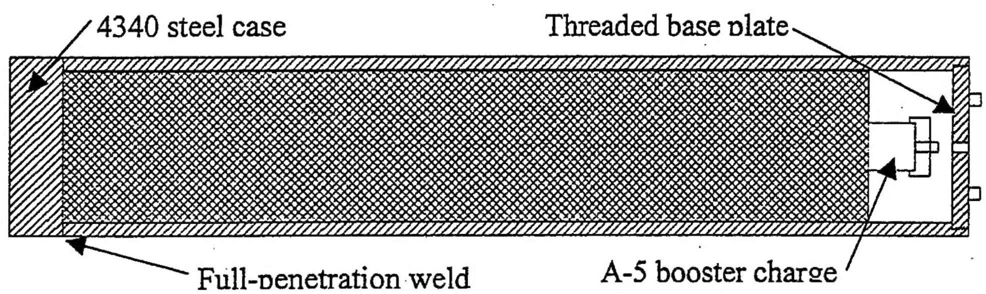


Figure 5. Cross-Section View of Cased Cylinder

TEST SETUP AND RESULTS

Approximately thirty channels of blast pressure gages were fielded in the surface flush mounts of the instrumented blastpad. Figure 6 shows the pressure gage layout for all of the tests. Positions where gages were present are denoted by blue x's. Each gage location is identified by an alpha-numeric name that indicates both its distance from the center of the pit and its azimuth with respect to the charge. Each radial is labeled from "A" to "J" in 22.5° increments, with the "A" radial (0°) being the "tail" of the item where detonation is initiated. Each position along a given radial is assigned a number that increases with range from the detonation pit. So for example, position "E7" lies at 5.80 m at 90° (broadside to the charge), position "G3" is at 2.80 m at 135°,

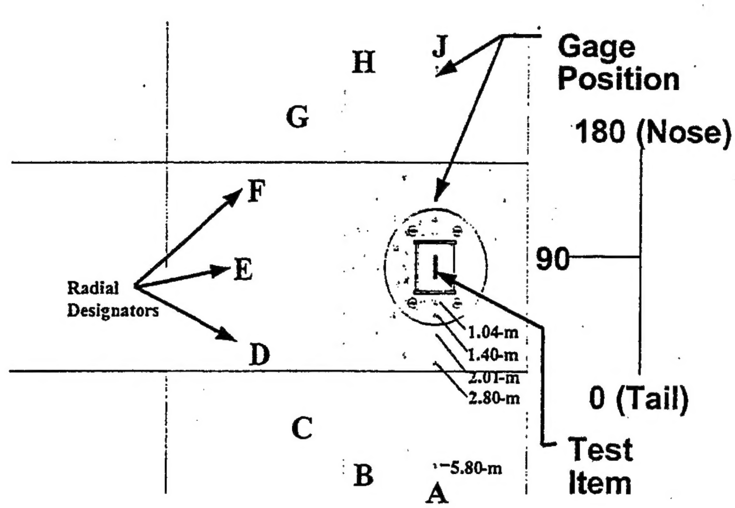


Figure 6. Gage layout for cased tests

etc. The blast pressure gages were piezoresistive diaphragm-based pressure transducers. The three generic penetrators were detonated first, followed by the three cased cylinders. The series of six tests occurred over a span of more than a year from late 2001 to early 2003.

The charges were positioned in the replaceable detonation by resting it in a cradle of polystyrene foam. This foam block was in turn supported by a wooden frame some 45 cm below the charge that was capable of height adjustment. This arrangement allowed for the precise vertical and horizontal alignment of the charge within the pit. Each item was positioned such that the centerline of the device was in the same plane as the blastpad's surface, while the center of gravity of the explosive (not that of the overall device) was in the center of the pit. Photographs that illustrate the positioning system can be seen below in Figure 7.

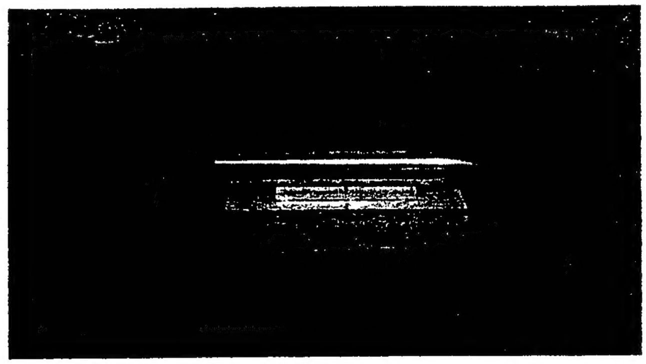



Figure 7. Positioning of each charge in the replaceable detonation area

Shown below are a few of the waveforms generated from the generic penetrators and cased cylinders. While six tests were performed, each of the following figures only shows two waveforms for the sake of clarity – one for a cylinder and one for a penetrator. Explosive tests never exactly duplicate one another, but each waveform shown was selected to be largely representative of the other two tests in the series. First, Figure 8 below shows two waveforms from position C2, which is 2.01 m at 45° from the tail of the charge. As one can see, the peak pressures, peak impulses, and general character of the waveforms are extremely similar.

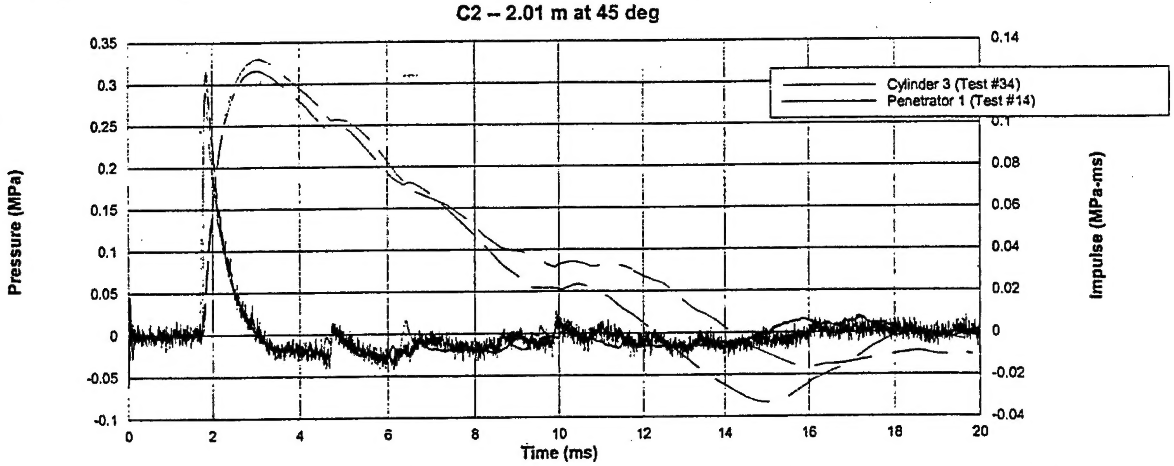


Figure 8. Comparison of Cased Cylinder and Penetrator Waveforms at Position C2

The same can be said of the mirror image position, G2, which is located at 2.01 m at 135° (45° from the nose). These waveforms can be seen below in Figure 9. Once again, the cased cylinder and the generic penetrator perform very much the same.

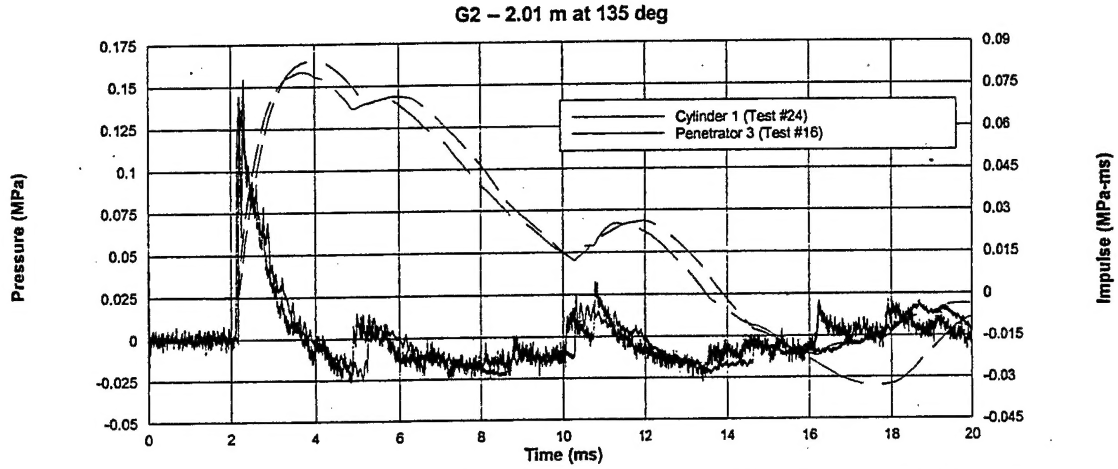


Figure 9. Comparison of Cased Cylinder and Penetrator Waveforms at Position G2

However, the agreement between the two charges is not always so exact. It became apparent while examining the other waveforms that in some areas there appeared to be some substantial differences. When just looking at peak pressures, position B2 stood out as having very dissimilar values. However, when plotted (see Figure 10) the differences are perhaps not so severe as they first appear. The slow rise time of the cased cylinder signal could possibly indicate a faulty gage incapable of capturing the sharp peak of the pressure signal. Or the high peak could itself be erroneous. In any case, the fact that the total impulses of the charges are very similar, as are the general characters of the waves, indicates that the charges are likely not dissimilar in this case after all.

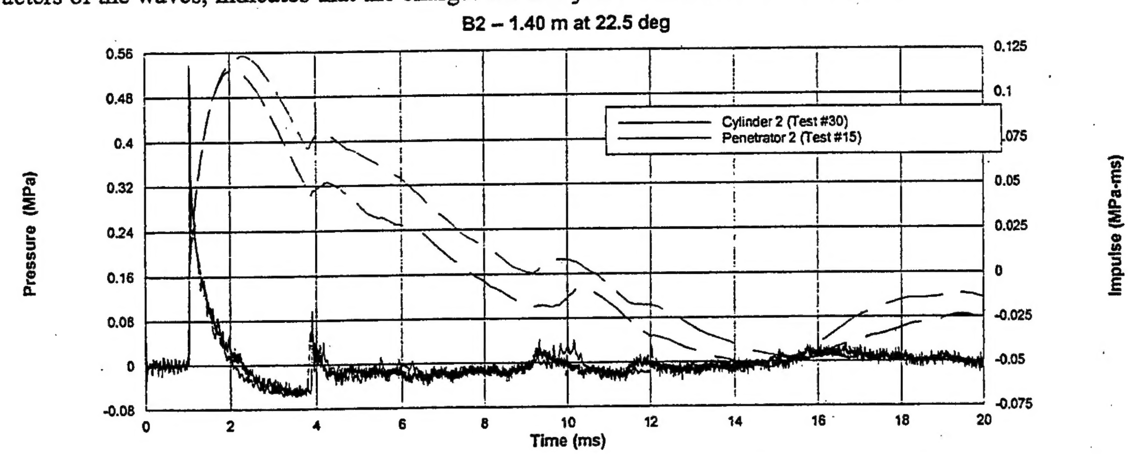


Figure 10. Comparison of Cased Cylinder and Penetrator Waveforms at Position B2

In order to more easily visualize the blast field around each device, the peak values for each series of three tests were averaged to give a single blast field for each type of charge. These values were then used to generate surface contour plots of peak pressure, peak impulse, and time of arrival over the entire area of the blastpad. An example of one of these contour plots is shown below in Figure 11. This particular plot shows the average peak impulse field generated by the cased cylinders. A complete array of contour plots for peak pressure, peak impulse, and time of arrival for both the cased cylinders and the generic penetrators can be found in Appendices A and B. The contours are displayed as if one were looking down on the blastpad surface from overhead. As such, the explosive is located at (0,0), with the nose of the item pointed to the right and the tail oriented to the left. Locations where measurements were taken are marked with a black dot, and the interpolated surface contours were generated by a 3-D plotting program called Surfer.

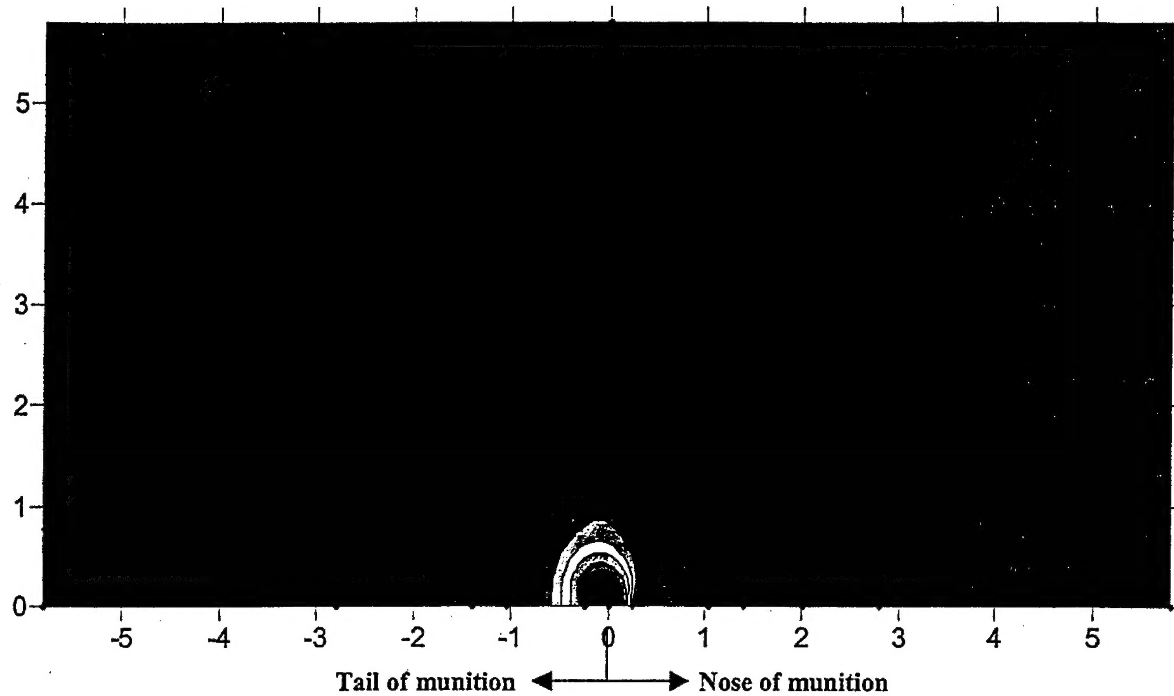


Figure 11. Impulse Field from Cased Cylinders

By visually comparing the fields for cased cylinders and generic penetrators, it becomes possible to identify locations where the two charges have substantial differences. However, a more illustrative method involves generating a "residual" plot that displays the percent difference between the average measured values for the two charges. The equation used to calculate this residual is shown below.

$$residual = \frac{P_{penetrator} - P_{cylinder}}{P_{cylinder}} * 100\% \qquad (1)$$

In this equation P is the peak pressure, though the formulation for impulse and time of arrival (TOA) residuals is the same. With this formulation, if the pressure generated by the generic penetrator were double that of the cylinder, it would show up as a 100% residual, while a value of –50% would indicate that the penetrator only produced half the pressure that the cased cylinder did. Plots of residuals can be found below in Figures 12-14.

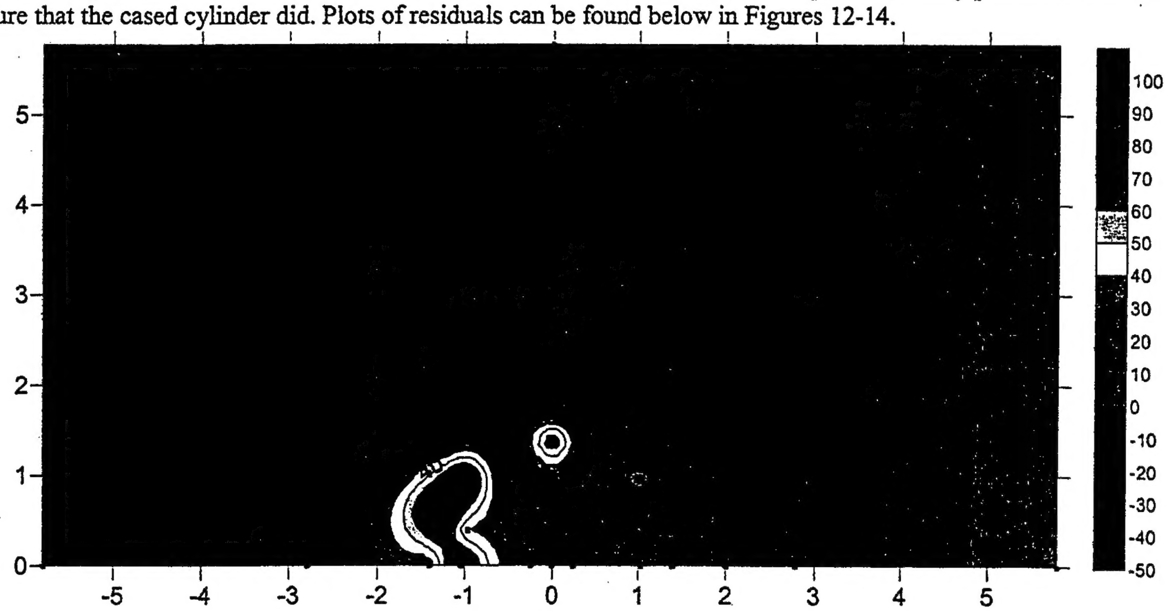


Figure 12. Pressure Residual Plot for Penetrator vs. Cylinder

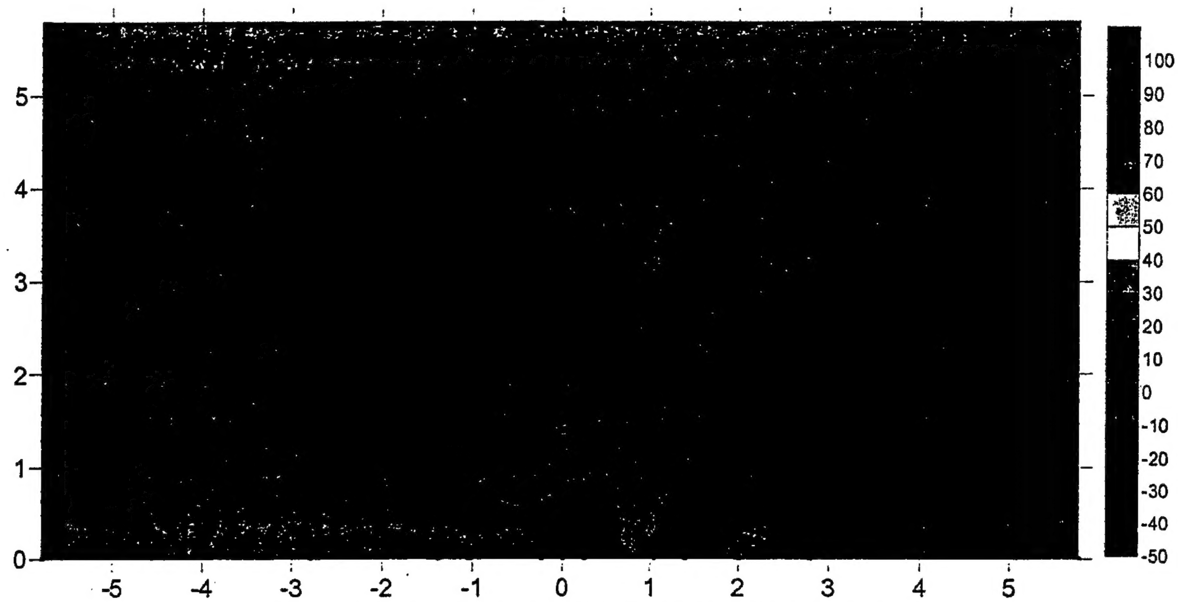


Figure 13. Impulse Residual Plot for Penetrator vs. Cylinder

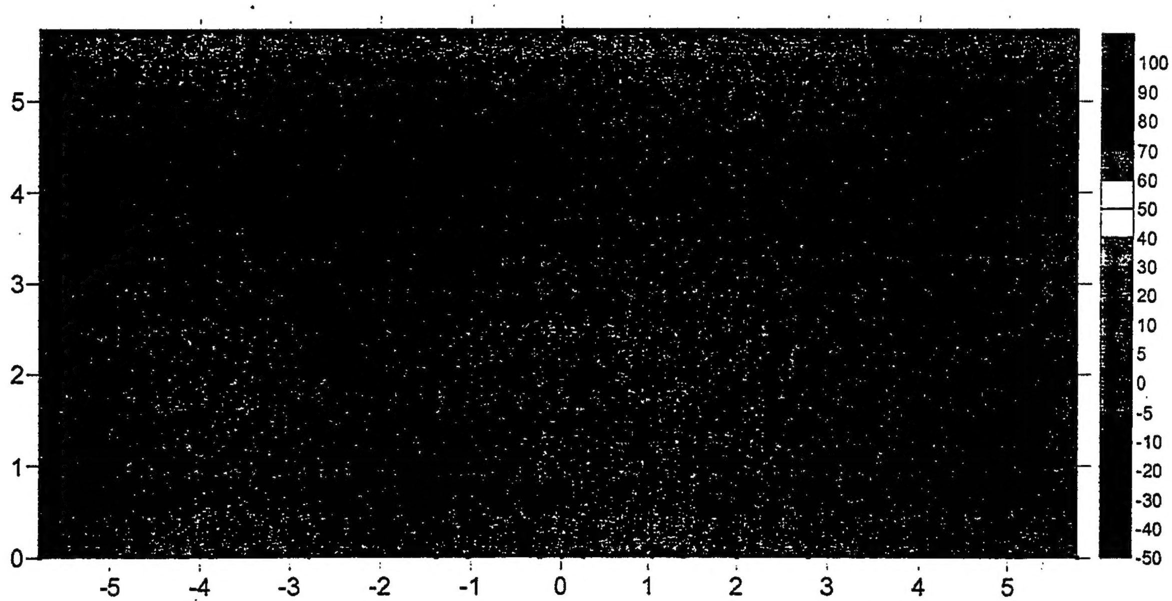


Figure 14. Time of Arrival Residual Plot for Penetrator vs. Cylinder

The first thing to note about the pressure field in Figure 12 is that while many of the penetrator pressures are within +/- 10% of the cased cylinder, there are some large areas towards the side and rear of the charge where the penetrator measured pressures are upwards of 50% greater than those from the cased cylinders. However, examination of the waveforms at the locations with the largest differences tends to reveal large test-to-test variations, questionable measurements, or at least one instance where no data at all was captured. In other words, the locations with the largest apparent discrepancies in peak pressure are also the ones with the highest statistical uncertainties. Furthermore, in some cases (such as B2, shown in Figure 10) the peak pressures were very different while the impulse, TOA, and wave shape were still very much the same. It has long been known that peak pressure measurements are not always the most reliable of data, and this set of experiments seems to bear out that statement. It is therefore difficult to draw a firm conclusion as to the suitability of surrogating a sub-scale munition with a cased cylinder from this plot alone.

In contrast, the plot of peak impulse residuals, Figure 13, appears much more well-behaved. The vast majority of measurements are within +/- 10% of each other. Only a few points show residuals higher than that, and they once

again are locations with high statistical uncertainties associated with them. This plot of peak impulse residuals strongly suggests that a sub-scale munition can be accurately represented by a cased cylinder.

The plot of TOA residuals shown above in Figure 14 tells much the same story. In this case, almost all the measurement locations showed residuals within +/-5% – excellent agreement for explosive tests. As with the plot of impulse residuals, these contours strongly suggest that the blast field for a sub-scale munition can be simulated reasonably well by tests using a cased cylinder surrogate.

CONCLUSION

Testing of cased explosive charges has largely been performed with cased cylinders of explosive rather than actual sub-scale munitions for a variety of reasons. However, the accuracy of this surrogation has never been verified. The Air Force Research Lab Munitions Directorate undertook an experimental effort to try and resolve this issue using it Instrumented Blastpad. Six tests were performed – 3 generic penetrators and 3 carefully designed cased cylinders that served as surrogates for the penetrators. It appears from these tests that the technique of approximating a sub-scale munition with a cased cylinder is indeed a valid practice, but the conclusions are not as certain as a modeler may wish them to be. However, it is reasonably safe to say that, at best, there is very little to no difference between the blast fields generated by a sub-scale penetrator and a suitably designed cased cylinder surrogate. At worst, the impulses and times of arrival are closely matched, while there are some questionable peak pressure locations.

REFERENCES

1. Ohrt, A. and Blaney, E. "A Test Apparatus for Measuring Airblast Pressures From Cased Charges." Paper presented at the 17th International Symposium on the Military Aspects of Blast and Shock, Las Vegas, NV. June 2002.

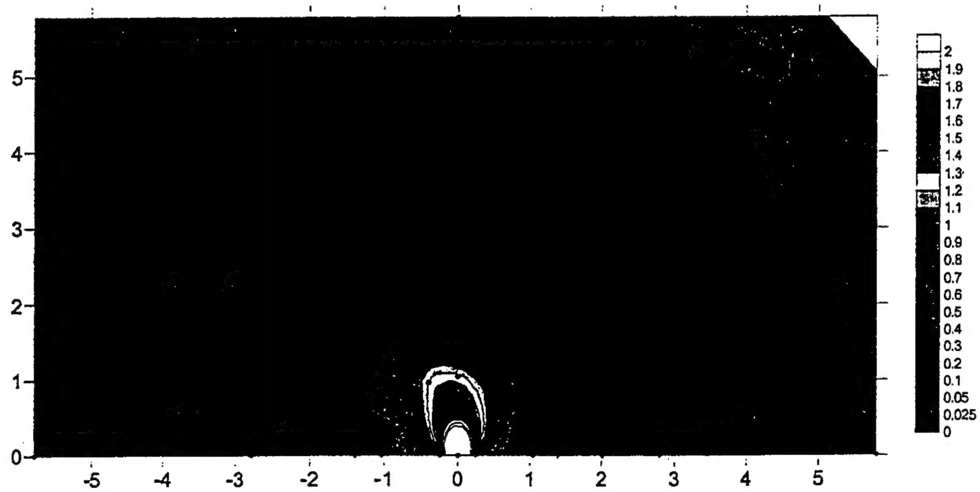
2. Ohrt, A., Lindner, T., and Lee, S. "A Study of the Effect of Casing Mechanical Strength on the Airblast Field From a Cased Charge". Paper presented at the 18th International Symposium on the Military Aspects of Blast and Shock, Bad Reichenhall, Germany. September 2004.

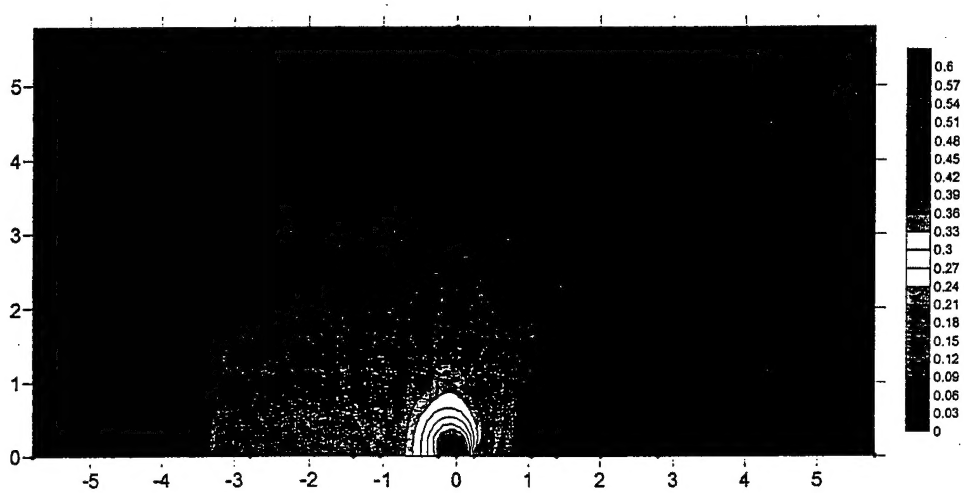
3. Blaney, E. and Ohrt, A.. "Design, Construction, and Utilization of an Instrumented Blastpad", Paper presented at the 72nd Shock and Vibration Symposium, Destin, FL. November 2001.

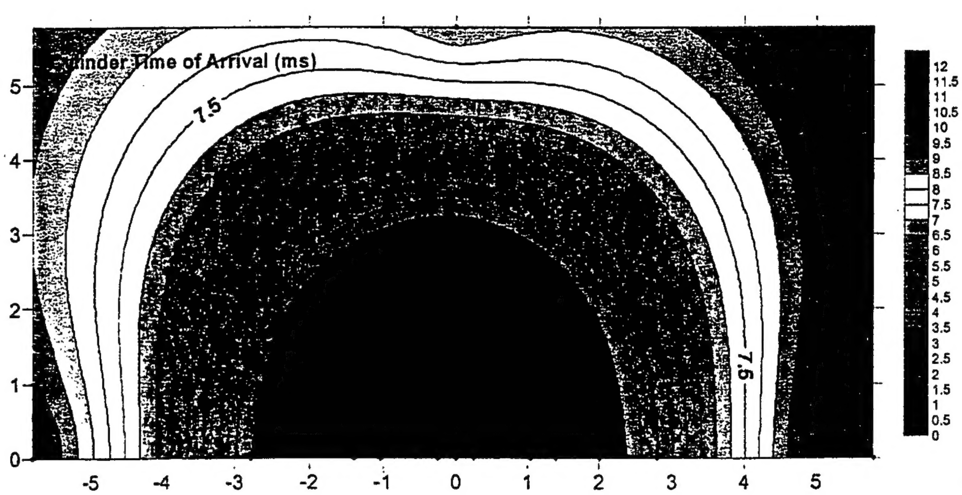
4. Blaney, E. and Ohrt, A. "Influence of Case Mass/Explosive Mass Ratio on a Munition's Airblast Field." Paper presented at the 73rd Shock and Vibration Symposium, Newport, RI. November 2002.

5. Ohrt, A. and Blaney, E. "Measured Airblast Fields From Cased Explosive Charges Having Different Explosive Fills." Paper presented at the 73rd Shock and Vibration Symposium, Newport, RI. November 2002.

APPENDIX A – CASED CYLINDER CONTOUR PLOTS







APPENDIX B – GENERIC PENETRATOR CONTOUR PLOTS